JPL

Cassini-Huygens Probe On-Pad Cooling Incident

Report of Formal Review Board

Harry K. Detweiler, JPL, Chair

C. Nelson Carter, JPL, Secretary

Hans Bachmann, ESA

Benjamin Bier, Lockheed Martin

Timothy W. Larson, JPL

Charles E. Lifer, JPL

Duncan MacPherson, Consultant

Ronald A. Miller, GSFC

Alan Moseley, ESA

Richard L. Stoller, JPL

October 27, 1997

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Cassini-Huygens Probe On-Pad Cooling Incident

Report of Formal Review Board

1 Introduction

1.1 The Board

In accordance with JPL Standard Practice Instruction 4-18-1, *Accident, Incident, or Mission Failure Reviews,* a Review Board was appointed by JPL Deputy Director Larry Dumas, via a letter dated September 17, 1997 (Appendix A). The members of the Review Board are:

Harry Detweiler, JPL, Chair
Hans Bachmann, ESA
Benjamin Bier, Lockheed Martin
Nelson Carter, JPL, Board Secretary
Timothy Larson, JPL
Charles Lifer, JPL
Duncan MacPherson, Consultant
Ron Miller, GSFC
Alan Moseley, ESA
Richard Stoller, JPL

The Review Board was chartered to:

a. Determine what actually occurred in the on-pad cooling incident.
b. Determine the root cause of the on-pad cooling incident.
c. Identify steps that should be taken in the future to prevent similar occurrences.

The Board's investigations were to be implemented in parallel and on a noninterference basis with the ongoing Cassini launch preparations. The scope of the Board's investigation was limited to the activities leading up to and including the cooling incident on the launchpad.

1.2 The Incident

On 28 August 1997, while the Cassini spacecraft was on the launchpad and mated to the Titan IVB/Centaur, a cooling incident occurred affecting the Huygens Probe. Because of probe internal heat dissipation, cooling was required to maintain the probe hardware within thermal specifications. It has been determined that cooling air at about 0.26 kg/s (35 lb/min) was injected from the facility cooling system directly into the probe descent module (DM), producing high-velocity airflow in the vicinity of internal probe insulation. A borescope examination performed on 2 September showed a tear approximately 5 cm (2 in.) long in a Kapton blanket and particles of insulating foam inside the DM.

Because of possible unseen damage inside the DM, the spacecraft was removed from the launchpad and returned to the Payload Hazardous Servicing Facility (PHSF). The probe was then removed, opened, thoroughly inspected, cleaned, repaired, and reverified. It was then reinstalled on the spacecraft and transported back to the launchpad. These unplanned activities resulted in a delay of seven days in the scheduled launch of the Cassini-Huygens mission.

1.3 Summary of Board's Findings

After reviewing the available documentation and interviewing various personnel from each of the organizations involved, the Board concluded that the anomaly was caused by deviations from program policies and practices in failing to define, communicate, and document changes in interface requirements. In particular, there was a failure to communicate necessary information across the JPL/ESA interface, leading to inadequate documentation of probe cooling requirements and launch operations procedures.

1.4 Summary of Recommendations

In order to avoid similar incidents in the future, the Board recommends, among other things, that more rigorous attention be paid to the documentation of requirements, changes, and procedures. A further recommendation is that lines of communication between personnel working on ground support equipment (GSE), flight hardware, and test and launch operations on both sides of the organizational interfaces be improved and that such personnel be involved more closely in the periodic reviews held on the program.

2 Investigation Procedure

The Board convened on 19 September 1997 at JPL. All members were present in the Cassini conference room (264-439), except Ron Miller, who participated via teleconference from Goddard Space Flight Center (GSFC), MD. The Board heard an overview briefing by JPL's Probe Integration Manager, who furnished the Board with copies of numerous relevant documents, including the Problem/Failure Report on the incident. He also assisted the Board by arranging for a number of involved individuals to be available for interviews.

The Board then traveled to Kennedy Space Center, FL, where the ten members met daily for four days, conducting individual interviews with about 12 JPL employees and five employees of ESA and its contractors, all of whom had personal knowledge of facts surrounding the incident. During this time the Board also reviewed additional documents and held in-depth discussions to arrive at conclusions about what actions or omissions had led to the incident.

After leaving the Cape, the Board reconvened on 29 September via teleconference, with one member at Lockheed Martin in Colorado, one at GSFC, and one at ESTEC in the Netherlands, where five more employees of ESA and its contractors were interviewed individually by the Board.

On 6 October the Board convened again to interview an additional ESA employee by teleconference from Europe.

3 Findings and Recommendations of the Board

The responsibility for supplying ground air for cooling the probe on the launchpad was informally transferred from ESA to JPL without adequately defining the resulting new interface requirement, documenting and reviewing it, or developing a complete plan for its implementation. In addition, the internal probe cooling configuration for the launchpad was changed without adequate review and coordination. The combination of these two omissions resulted in excessive cooling-air velocity within the probe descent module, which caused damage. What occurred in the on-pad cooling incident is documented in the Problem/Failure Report (PFR), which is presented as Appendix B. A chronology describing key events leading up to the incident, plus

Board observations and evaluation comments, is given in Appendix C, which provides additional details in support of the Board's findings.

3.1 Root Cause of Cooling Incident

The root cause of the on-pad cooling incident is deviations from program policies and practices. These deviations led to inadequate documentation of probe cooling requirements and subsequently to inadequate documentation of launch operations procedures. These inadequacies were recognized by the Program after the incident. The probe cooling requirements were then appropriately defined, and detailed launch operations procedures were generated prior to the first meeting of this Review Board. Recovery from the incident was accomplished, although it caused a one-week delay in the scheduled launch date. The important issue for this inquiry was to understand how these process failures could have occurred so that actions can be implemented to prevent similar incidents in the future.

The general procedures and practices in place on the Cassini Program to identify and ensure compliance with all requirements are adequate. The inadequate documentation of the probe cooling requirements is a result of not complying with those procedures and practices, accompanied by unfortunate circumstances and lapses in good engineering/management practice. The requirements for probe cooling remained undocumented, in all likelihood because they applied to mechanical GSE, which usually has less detailed requirements. The interface to the flight probe due to use of air conditioning from the launch complex apparently was not recognized or adequately considered as constituting a risk. Even so, it is unlikely that the probe would have been damaged if proper change control, documentation, and review had been implemented when the planned probe cooling configuration for the pad was changed late in the program.

All of these aspects are discussed in the following sections of this report. Section 3.2 describes the deficiencies in implementing the program policies and practices that should have formally documented the probe cooling requirements. There was also ample opportunity for information exchange that could have prevented the probe cooling incident from occurring, even in the absence of formal documentation of the probe cooling requirements. The issues and actions that led to inadequate understanding of the probe cooling requirements and the resulting inadequate documentation of launch operations procedures are numerous, and a good case can be made that elimination of any one of these issues or actions would have prevented the anomaly. The issues are primarily unfortunate circumstances, discussed in Section 3.3. The actions are primarily lapses in good engineering/management practice, discussed in Section 3.4.

It is important to note that the actions taken during the probe cooling incident were logical, based on the knowledge available to the people taking the action. The probe cooling incident was entirely due to inadequate/imprecise information exchange.

3.2 Inadequate Documentation of Probe Cooling Requirements

The following subsections discuss the deficiencies in implementing the program policies and practices that should have formally documented the probe cooling requirements.

3.2.1 Probe Interface Requirements Document (IRD) PD-699-080

The requirements for probe cooling could have been satisfactorily documented other than in the IRD, but many program members now indicate that IRD documentation would have been appropriate. (The Board concurs.) Including documentation of the probe cooling requirements in the IRD is consistent with inclusion of the ground power requirements, which are detailed in IRD Section 3.2.4.2. In any case, the program did document the original responsibility for probe cooling (the only requirement for probe cooling that then existed) in Section 3.2.3 of the IRD, as follows:

> "3.2.3 Ground Cooling
> ESA shall provide ground cooling as is required to support the probe system integration, test, and launch activities."

The decision to include the responsibility statement of Section 3.2.3 was made to clearly establish a simple requirement: ESA is responsible (hence there is no JPL/ESA interface for this item). This provision was violated by the lack of any action to change Section 3.2.3 when the responsibility became split between ESA and JPL (ESA up to transport to the pad, at which point JPL became responsible), and an interface was created. This absence of an IRD update seems to be a clear violation of program policies, although the incident could have been avoided by adequate documentation in another form.

3.2.2 Specification Compliance

The effect of the absence of an IRD update was compounded when the specification compliance matrix was produced. The item pertaining to Section 3.2.3 of the IRD was marked N (for Not a Requirement or Not Applicable) in this matrix, thus overlooking the fact that the probe cooling responsibility and implementation were not as described. It appears that this could have occurred only in one of two circumstances: The evaluation either

(a) did not consider a responsibility statement as needing verification, or

(b) was made in a less than rigorous fashion without adequate consideration of the requirement and possible consequences.

There does not appear to be another alternative, and neither of these is particularly encouraging relative to the question of whether there are other omissions or problems in the probe interfaces. The whole purpose of the compliance matrix is to ensure that requirements have been met, and not detecting the inconsistency between the IRD and the actual implementation represents a clear failure of the process.

3.2.3 Recommendations

There were two serious policies and practices problems involving the IRD: The first was not updating the document when changes were made in the probe cooling approach and responsibilities, and the second was improperly evaluating conformance in the verification matrix. A specific recommendation relative to the first problem would be to require that program decisions made at the working-group level, or at program reviews, that affect interfaces automatically trigger a review of the need to change the IRD or Interface Control Drawing (ICD). This review should involve all affected organizations and should include an assessment of the potential impacts to all systems and subsystems prior to final implementation. To address the second problem, the verification methodology must be thorough and must consider responsibility statements as well as requirements.

3.3. Contributing Issues

Contributing issues are characteristics of the program or process that existed over an extended period of time and were factors in inadequate documentation of the probe cooling requirements and/or the inadequate documentation of launch operations procedures. The following subsections discuss these issues, which are primarily unfortunate circumstances. Recommendations for dealing with these issues follow the discussion of each issue.

3.3.1 Stacked-Probe Cooling Was an Orphan

Stacked-probe (probe mounted on the spacecraft) cooling is an interface issue sufficiently different in concept and implementation from other interfaces that it has no "home" in the program infrastructure where it can be monitored at an appropriate management level. This effect is conveniently illustrated by considering the spacecraft science instrument purge flow function. That function is very similar in important ways to the probe cooling function, but is different in that it affects several science instruments. The spacecraft science instrument purge flow requirements were investigated, evaluated, negotiated, and collected in a document that defined these requirements clearly and completely for the program. This was recognized as a major issue and monitored by senior program personnel and management throughout the process, and the end result was presented in a design review. The plain fact is that the implementation of probe cooling was not a significant concern to senior management on either side of the interface. Everybody knew it needed to be done, but it was not considered a significant technical issue, and the implementation details were of concern only at the working level.

As can be seen in the chronology (Appendix C), the probe ground cooling plan using facility air conditioning was discussed for a long time (starting circa November 1994) without closure ever being achieved on the details. There was ample opportunity for this situation to be dealt with in any of several ways. For example, JPL could have documented their detailed plans for implementing cooling air flow, including specific flow rates, and presented them in one of the quarterly reviews ("one-sided" documentation). Alternatively, the flow rates could have been indicated as "set to TBD (value to be supplied by ESA)" to highlight the need for detailed information, or an action item could have been opened requesting ESA to supply the flow rates. Other possible approaches include elevating the issue within JPL or formally notifying ESA. However, the JPL people involved did not employ any of these means, and little or no management guidance or help was provided in pursuing these approaches.

The message for the future here is that management needs to be more responsive in helping people get information and deal with other communication problems.

3.3.2 Ground Cooling Not Considered a Design Issue

Despite the instrument purge analogy cited in 3.3.1, there appeared (generally, but not universally) to be a pre-incident attitude that cooling was "only a GSE issue" and so could be treated less rigorously than flight hardware. This exception did not seem to extend to GSE hardware that touches flight hardware, so perhaps the potential physical hazard was not recognized. In any case, it seems quite clear that, prior to the incident, the probe cooling issue was generally viewed much less seriously than other issues that affected flight hardware. A Failure Modes and Effects Criticality Analysis (FMECA) on the probe cooling process was not done (as had been done for the instrument purge implementation). There was an interface to flight hardware with the potential for damage that was not properly assessed.

Future programs should ensure that processes that are similar are treated similarly in project planning and implementation. It is necessary to be especially watchful with GSE interfaces to the flight hardware. In particular, the approach to mechanical GSE, especially when it has a dynamic interface with the flight hardware, must ensure that the interfaces, the requirements, and the impacts are well understood and documented.

3.3.3 Communication Problems

At program inception, ESA and JPL recognized that the complexity of the probe/spacecraft interface could present problems in the absence of good communications. To forestall this, the program management tried to establish good technical communications, primarily through the working-group process. While this provided a medium for airing technical issues, the relevant working-level people did not often attend, but were represented by others. Although direct contact at this level was not discouraged, it was not actively encouraged either. Large distances and time differences, and to some extent language, organizational, and cultural differences, along with ESA's need to be a party to all decisions and agreements, inhibited practical utilization of this communication process.

In this particular case, there was no effective direct working-level technical interchange on probe cooling flow rates, which could have prevented the incident. To compound this problem, the on-pad air conditioning provisions fell into a "gray" area, with responsibility considered to be shared between the Assembly, Test, and Launch Operations (ATLO) and Mechanical/Thermal working groups, with oversight by the Systems working group. These groups did not communicate well enough to assure the acceptability of the ground cooling provisions or to identify the failure to adequately document the probe cooling interface.

Both ESA and JPL might have taken extra care to ensure that all details were well handled if they had been more sensitive to their differences in communication techniques. Management must not only allow but facilitate effective communication, and must put in place means for assuring it is occurring. The length of time the plan for ground cooling of the probe was unresolved should have signaled the existence of a communication problem in need of correction.

3.3.4 Diverter Box Capability

JPL designed a piece of mechanical GSE, the diverter box, to control the cooling air to the probe, as well as to provide a means for inflating the spacecraft protective bag during the hoisting operation at the launchpad. It was designed to be very flexible in order to accommodate any flow rate that might be desired at any time. Ironically, this capability contributed to the cooling anomaly. The problem was that everyone who had an interest in, or responsibility for, probe cooling acted as if no problem were possible, with the undesirable effect of eliminating most of the impetus to force communication across the interface to tie down details.

The message here is that the process is not complete until the details are worked out, agreed to by both sides of the interface, *and documented.*

3.3.5 Overload

The JPL engineer with primary responsibility for the stacked-probe cooling was also responsible for other higher-priority tasks and was working long hours as a result. It is well known that this kind of overload environment does not permit time for contemplation directed at uncovering more problems. This could have been a factor in the communication breakdown across the interface because there was little or no possibility of simple (non-time-consuming) communication (see 3.3.3 above). It could also have been a factor in the inadequate documentation of launch operations procedures.

Management needs to be sensitive to situations where personnel overload can occur and make staffing decisions to preclude it whenever possible, or take appropriate steps to mitigate the increased technical risk if it is not.

3.4. Contributing Actions

Contributing actions are specific acts or activities that occurred in some specific time period and were a factor in the inadequate documentation of the probe cooling requirements and/or the inadequate documentation of launch operations procedures. The following subsections discuss these actions, which are primarily lapses in good engineering/management practice. Recommendations for eliminating the problems follow the discussion of each action, but these tend to be simply eliminating the deficiencies.

3.4.1 Maximum Flow Rate Documentation

A fax dated 26 Jan 95 from Aerospatiale provided an answer to an action item (AI) requesting information on nominal and maximum flow rates. This fax states:

> "The gas flow rate to be used for air venting between DM and ENA is still under evaluation.
>
> The present value used by DASA in their calculations is <u>0.04 kg/s</u>.
>
> Anyway, the flow rate has to be limited to about <u>0.3 kg/s</u> to avoid any damage inside the probe (it corresponds to air velocity inside the hose of about V = 16 m/s and delta pressure of $\Delta P \approx 150$ Pa).
>
> The flow rate will be confirmed after tests performed on STPM."

A drawing attached to that fax showed a 6-in.-diameter hose. Later documentation confirms the desired flow rate (0.04 kg/s), but neither the maximum flow rate (0.3 kg/s) nor the 6-in.-diameter hose was ever mentioned again. The JPL reaction to this AI response was to determine that the maximum flow rate of 0.3 kg/s (about 40 lb/min) could be provided by the diverter box, so there was no concern over the possibility of inadequate probe cooling. This knowledge created two beliefs at JPL: first, that stacked-probe cooling was not a concern, and second, that limiting flow rate to 40 lb/min would prevent damage to the probe.

All of the actions taken by JPL during the cooling incident were consistent with complying with the 40-lb/min flow rate as a damage limit not to be exceeded at any time. This was a result of their firm belief that this was the damage limit. That belief (shown by the probe cooling incident to be erroneous) was not unreasonable, given that they had never been provided with any other value.

The need to update limit values as appropriate is obvious. Furthermore, the AI should not have been closed by the fax, which did not state a requirement and indicated work still had to be done unless another AI was generated to firm up the requirement.

3.4.2 The Descent Module Cooling Decision

The configurations defined for the various phases of probe processing in the USA are called out in Table 2 of the Huygens Ground Cooling System Specification (Appendix D). There are two modes for internal probe cooling during the last stages of processing: (1) flow through the DM, and (2) flow between the DM and ENA (ENtry Assembly). The first mode was to be used in the final cleanroom processing prior to transport to the pad. The second mode was the baseline in 1995 for "on way to launchpad" and "on launchpad (probe is mounted on orbiter)" and remained so in the latest revision of that specification. However, the cooling configuration was left in the first mode for transport to the pad, resulting in the cooling air being injected directly into the DM during the on-pad cooling incident. Neither the date of this decision to change cooling modes for on-pad operation nor the factors in the decision process are known. Furthermore, how the decision was made was not determined. It seems clear that ESA considered this decision an entirely internal matter that had no effect on the probe interface, since JPL was not notified of the decision. The cooling incident shows that there were interface consequences to this decision.

ESA's belief that there were no interface consequences was not unreasonable. ESA assumed that they were going to get a 0.04-kg/s flow rate to nearly match that of the Galileo cooling cart used during earlier processing, regardless of the cooling mode. This flow rate would have been satisfactory in the DM cooling mode, as well as in the earlier baseline mode.

Some ESA personnel have claimed that the probe Launch Operations Manual (LOM) and/or the visible probe cooling ducting was, or ought to have been, adequate notification to JPL of this cooling mode change. The unreasonableness of this claim is exposed by the fact that at the time of the incident other personnel of ESA and its contractors, key to the process, were not aware of this decision to change the probe cooling mode and were surprised to learn that DM cooling had been used. It was confirmed that this could have been deduced from the LOM or the visible probe cooling ducting, but that had not been done before the incident.

The implementation of the decision to change the probe cooling mode casts considerable doubt on the stated beliefs by ESA and JPL management that communication and understanding across the interface were adequate. And the fact that key personnel of ESA and its contractors were not aware of the decision to change the probe cooling mode shows that this decision was not well communicated or documented, even within the Huygens Probe organization. Furthermore, the decision did not recognize any impact on the interface.

Lessons learned should include the need for a more structured, integrated procedure control process at the launch site, along with a process that fosters sharing of internal procedures and decisions.

3.4.3 Launchpad Airflow Values

The 26 Jan 95 fax from Aerospatiale (see 3.4.1) states that the airflow value being used is 0.04 kg/s, albeit with caveats that this is "under investigation" and "will be confirmed after tests performed on STPM." It seems reasonable that all parties should have adopted this 0.04 kg/s value as the best available estimate of the desired flow rate, with the understanding that this could change in the future. It seems odd that JPL did not do this when they embraced the maximum flow rate value (0.3 kg/s) that appeared in the same fax. Furthermore, the 0.04 kg/s did appear in later documents (although this documentation was relatively obscure to JPL), while the 0.3 kg/s (or any other) value for maximum flow rate was never mentioned again. Also included in the fax, but apparently unnoticed, was a drawing showing a 6-in.-diameter tube, which was used to compute the velocity into the probe cavity. No one picked up on that as part of the "requirement." The supply tube was later designed with a 4-in. diameter, which was clearly discussed and agreed upon. Nobody caught this as a problem.

JPL justifies the decision to split the flow rate from the diverter box equally between the probe and spacecraft (i.e., sending a flow of ≈ 0.15 kg/s to the probe in the initial launchpad configuration) on the basis that this was what was done on the Trailblazer exercise (see Appendix C) and that ESA was told orally that this flow would be used unless different instructions were given. There is no evidence that this plan or intent was ever documented in any written form, much less given to ESA in written form. This lack of documentation of planned airflow implementation is indefensible, independent of the inadequacy of the documentation of the desired 0.04-kg/s flow rate.

The message for the future is simple: The absence of appropriate documentation must not be allowed to happen.

3.4.4 Diverter Box Reconfiguration Procedure

There is now a consensus of opinion among program members that the procedure should have been explicit in defining the airflow rate that would be implemented and how to configure the diverter box for the launchpad cooling. (The Board agrees.) The JPL engineer who implemented the procedure did not view the absence of an explicit requirement with concern because this engineer's previous experience had been with procedures for which detailed requirements are not practical. Also, the procedure-writing process allows for heavy reliance on the cognizant engineer's knowledge of what to do and how to do it correctly. Furthermore, the engineer's management was aware and was not concerned.

Proceeding to provide cooling air to flight hardware based on parameter values having no documentation other than a two-year-old fax containing caveats relative to value finalization is not good practice. This situation was a result of the problems discussed above, but it should not have been accepted.

It should be noted that the ESA personnel at the Cape were also uncertain about the correct value of the airflow limit when consulted during the cooling incident, and phone calls to Europe were made to get this information. This is an illustration of how pervasive the lack of probe cooling flow information was.

The bottom line is that the absence of explicit requirements on airflow rates should have been noticed and rectified as part of the operating procedures process. The corrective action is to be more thorough.

3.4.5 Operations at the Launch Site

The ESA/JPL process for managing probe interface requirements and operations at the launch site was not well disciplined. ESA produced a Launch Operations Manual that was characterized as their project "bible" for all their activities at the launch site. Clearly, neither ESA nor JPL personnel on site treated the LOM as a controlling document after the probe was mated to the spacecraft. It was variously represented by them as containing reference or interesting information at most.

Perhaps more important is the fact that its function was not accomplished by some other document(s) in any rigorous manner. The process was run via JPL-produced procedures, schedules, and a series of meetings. This could work if each side's requirements were known, negotiated, and agreed to. In this case, the process failed to assure that the ESA requirements were known and met.

Two improvements seem prudent: The first is a more rigorous requirements negotiation/maintenance process at the site, and the second is a more rigorous and disciplined, integrated procedure-writing process where interfaces are involved.

4 Summary

The Cassini-Huygens Probe cooling incident was a result of a significant failure to effectively communicate through both formal (via established policies and practices) and informal (via good engineering/management practice) channels. The failure was significant on both the JPL and ESA sides of the interface. The communication problems were primarily a consequence of the JPL/ESA interface either directly or indirectly, and they were exacerbated by a variety of unusual circumstances related to probe cooling. This situation suggests a unique problem, but this cannot be affirmed because the Board did not investigate other Program interfaces.

A significant message for future programs is that interfaces that are unusual or unfamiliar, such as the probe cooling interface in this case, need special attention to ensure that conventional good practice is followed in all particulars. Another significant message is that different organizations function and communicate differently; it is therefore essential to pay particular attention to how information is communicated across organizational interfaces.

The processes used by JPL and ESA rely heavily on people and their experience, expertise, personal initiative, and common sense. In a program such as Cassini, the sophistication and complexity of the interfaces demand the utmost in rigor and discipline. For future programs, the experience gained in this incident indicates that the focus should be in the areas of:

(1) Systems discipline, especially in maintenance of the requirements and handshaking the verification of requirements across the interfaces;

(2) Coaching/mentoring junior personnel assigned to critical tasks;

(3) Assuring effective communication at the working level; and

(4) Clearly defining roles and responsibilities.

Appendix A

Review Board Appointment Letter

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109-8099
(818) 354-4321

JPL

September 17, 1997

Refer to: 078.97/LND:nv

Dear Review Board Member:

Subject: Formation of Review Board for the Cassini Huygens Probe On-Pad Cooling Incident.

A Review Board for the Cassini Huygens Probe On-Pad Cooling Incident is hereby appointed.

The members of the Review Board are:

Harry Detweiler, JPL, Chair
Hans Bachmann, ESA
Benjamin Bier, Lockheed-Martin
C. Nelson Carter, JPL, Board Secretary
Timothy Larson, JPL
Charles Lifer, JPL
Duncan MacPherson, Consultant
Ronald A. Miller, GSFC
Alan Moseley, ESA
Richard Stoller, JPL

The Review Board will:

a. Determine what actually occurred in the on-pad cooling incident.
b. Determine the root cause of the on-pad cooling incident.
c. Identify steps that should be taken in the future to prevent similar occurrences.

The Review Board is instructed to begin operations during the week of September 15. Board investigations are to be implemented in parallel and on a non-interference basis with the ongoing Cassini launch preparations. The results are to be documented in a brief written report. I would also like an oral briefing by the Board at the conclusion of this review.

Sincerely,

Larry N. Dumas
Deputy Director

Appendix B

Problem/Failure Report
(PFR No. Z44098)

Project: CAS CASSINI	Written By: JPL JPL	Problem/Failure Date 08/28/97	Day of Year Day: 240 Hr: 00 Min: 00	Log# 426-SAF QA

Report Type: Formal/Prelaunch	Reference Designation	Nomenclature	Serial Number	Operating Time/Cycles	H/C
SubSystem	2080	Huygens Probe	FM		
1st Tier HW/SW					
2nd Tier HW/SW					
3rd Tier HW/SW					

Reporting Location	Problem/Failure Noted During	Specific Environment
JPL - Kennedy Space Center	Integration	Ambient

Procedure: Spacescraft Mechanical Integration to LV Rev: Para:

DESCRIPTION OF PROBLEM/FAILURE:
" PROBE COOLING ANOMALY AT LC-40 "
The basic problem stated, simplified, is that the Huygens Probe Descent Module experienced too high an air flow rate by the facility/diverter box provided air conditioning. See Attachment-1 for detailed explanation.
Attachment: 4 Pages

Originator	Date	Cognizant Engineer
Wirth, John	09/09/97	Wirth, John

VERIFICATION & ANALYSIS:
The first signs of damage were seen when the bore-o-scope investigation was performed at LC-40. With these results it was agreed to remove the Probe from the Orbiter at the PHSF. After the Probe was re-opened up the extend of the damage was seen. The cause of the failure is being reviewed by an inquiry board.
John Wirth
9/30/97

Cause of Problem/Failure: D1
Design: Specification

PARTDATA	Piece Part Name	Part Number	Serial #	Circuit Desig.	MFR	Log#	Defect

CORRECTIVE ACTION TAKEN:
The Probe was repaired and re-mated to the Orbiter. The ESA NCR-7501 was closed.
See Attachment-3, 3-pages "NCR Closure"
John Wirth
9/30/97
Also note comments in Issues relative to the Anomoly Review Board Report provided by T. Larson, and the fact that the second move to the pad had very detailed procedures for setting the valves on the diverter box and verifying the resulting flow rate to the probe.

Disposition of SubSystem or Assembly	Effectivity	SEF?	Alert Concern? N	Hardware Safety? N
Redesigned/Reworked/Retested	This Unit	Y	Mission Critical? Y	Personnel Safety? N

STS Criticality Code: NA	See PFR	ECR No.	Waiver No.	ISA No.	Safety Status
Not Applicable					

	Signature (Sec)	Date		Signature	Date
Contractor		/ /	Safety Engineer		/ /
Cognizant Engineer	J. Wirth	09/30/97	Product Assurance	R. P. Brace	10/09/97
Section Manager	D. Kindt	10/05/97	Instrument Manager		/ /
System Engineer	Curt Henry	10/06/97	Project Manager		/ /
Reliability	J. Arnett	10/04/97			

ISSUES:
****
Issues added on 10/01/97 at 07:09:07 PST by JWIRTH (03476)
The inquiry board results have not been released yet to determine the real cause of the failure.
John Wirth
****
Issues added on 10/01/97 at 16:51:00 PST by JARNETT (05171)
PRE's Preliminary Risk Assessment:If no one had noticed this and the probe had flown with the damage, I'm assuming we have a potential mission catastrophic failure due to a) loss of thermal protection of critical Probe electronics, combined with b) possible contamination of Probe instruments; and therefore Failure Effect

| = "3". From feedback I have through the Mission Assurance team at the Cape, sounds like the problem is fully |
| corrected and that A/C control of the Probe is now "nominal". Therefore I
recommend
FC/CA = |
| "1". As to
Cause
this
is
a
design/interface
specification problem and should be assigned a |
| Cause = D1, Design(Specification,ICD). Disposition is recommended to be
| RZ-Redesigned/Reworked/Retested.
** |
Issues added on 10/01/97 |
| at 16:49:08 PST by JARNETT (05171)
This P/FR has been forwarded to the ERE for review and concurrence. It is |
| recommended that the P/FR ramain open until the Review Board Report is issued and incorporated in the P/FR
| file.
** |
Issues added on 10/02/97 at 17:04:07 PST by AHOFFMAN |
| (36830)
Cassini Environmental Requirements (A. Hoffman) and T. Larson (Thermal analyst and 5XC anomaly review
| board member have reviewed the PFR offer the following comments:
The corrective action verifcation shoulld reference |
| the IR (or ESA equivalent)
generated by the QA
people that witnessed the repair. Also, the second move to the
| launch pad had very detailed procedures
for setting
the valves
on
the diverter box and veerifying the
| resulting flow rate to the probe.
T. Larson also notes that the board report will describe the root cause of the |
| failure, but will not address the repair/recoveryactivity. He suggests that it may not be worthwhile to hold the PFR open|
| for an additional 2=3 weeks until the report is released. A. Hoffman suggests closure prior to the report release because|
| the boards report will affect future missions, the Cassini problem has been worked.
T.Larson added a note |
| clarifying the timeline on Attachment 2.
We understand that an acoustic assessment was made and provided to the |
| program office. That report has not been evalutated by Environmental Requirements. We understand that there were no
| residual acoustic concerns.
We concur
| in
the
rating.
****
Issues added on 10/04/97 at 09:03:36 |
| PST by JARNETT (05171)
An Action Item has been assigned to the ERE to
acquire a copy of the
final |
| Inquiry
Board Report for incorporation in the archive file for this P/FR, post-closure. Additionally this P/FR has
| been designated as a candiate SSEF, and preparation of the SSEF summary has been assigned to Office 505. PRE recommends
| closure with no change in original preliminary risk ratings.
J. Arnett, 10/04/97
|
****
Issues added on 10/04/97 at 09:16:32 PST by JARNETT |
| (05171)
NOTE: The following additional comment was appended to Page 1 of Attachment 1 by T. Larson as part of his |
| review of this P/FR and is added to the Issues section by PRE as the scanned copy is not very readable:
" Pam |
| Hoffman's recollection is that the S/C bag outlet
valve was open
1/4 way in PHSF right before the cooling cart was |
| disconnected. Then, once at LC-40, all they had to do was open the inlet valve and connect the hose. This is a nit since|
| it doesn't matter whether the valve was set at PHSF or at LC-40. T.
Larson,
| 10/02/97"
****
Issues added on 10/06/97 at 15:08:42 PST by |
| JOKAMURA (06379)
I concur with the closure.
****
Issues |
| added on 10/09/97 at 06:35:40 PST by RBRACE (10537)
This PFR was reviewed and concurred with by Arden Acord and
| Chris Jones on 10/8/97.
Concur with closure of PFR before board report release and with suggestion of adding to |
| PFR when released.
|
|--|
| Failure Effect Rating: 3 |
| Failure Risk Rating: 1 |
| Last Processed @ PFO Center
| 10/09/97
============================== End of PFR 244098 ==============================

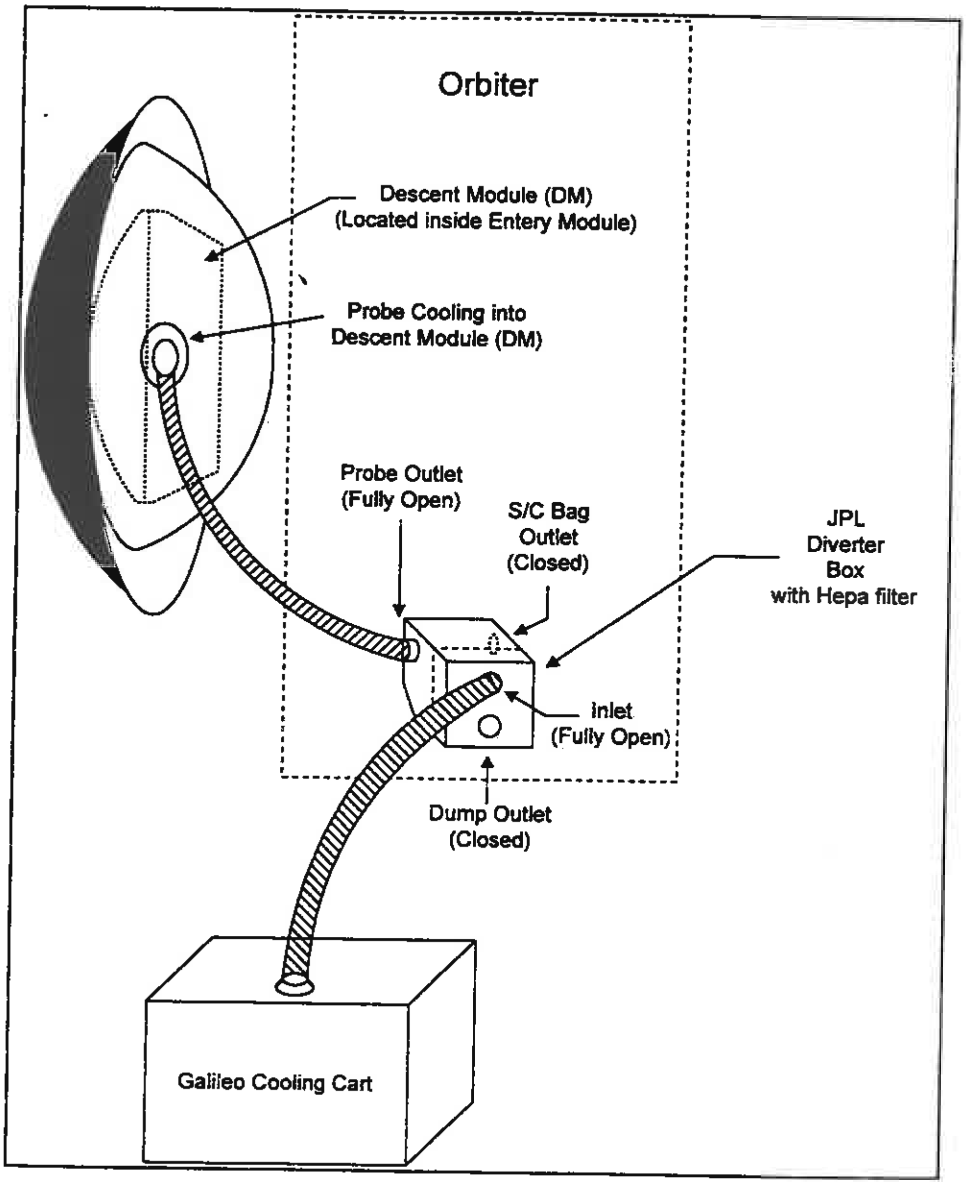
ATTACHED DOCUMENTS ON FILE.

Probe Cooling Anomaly at LC-40

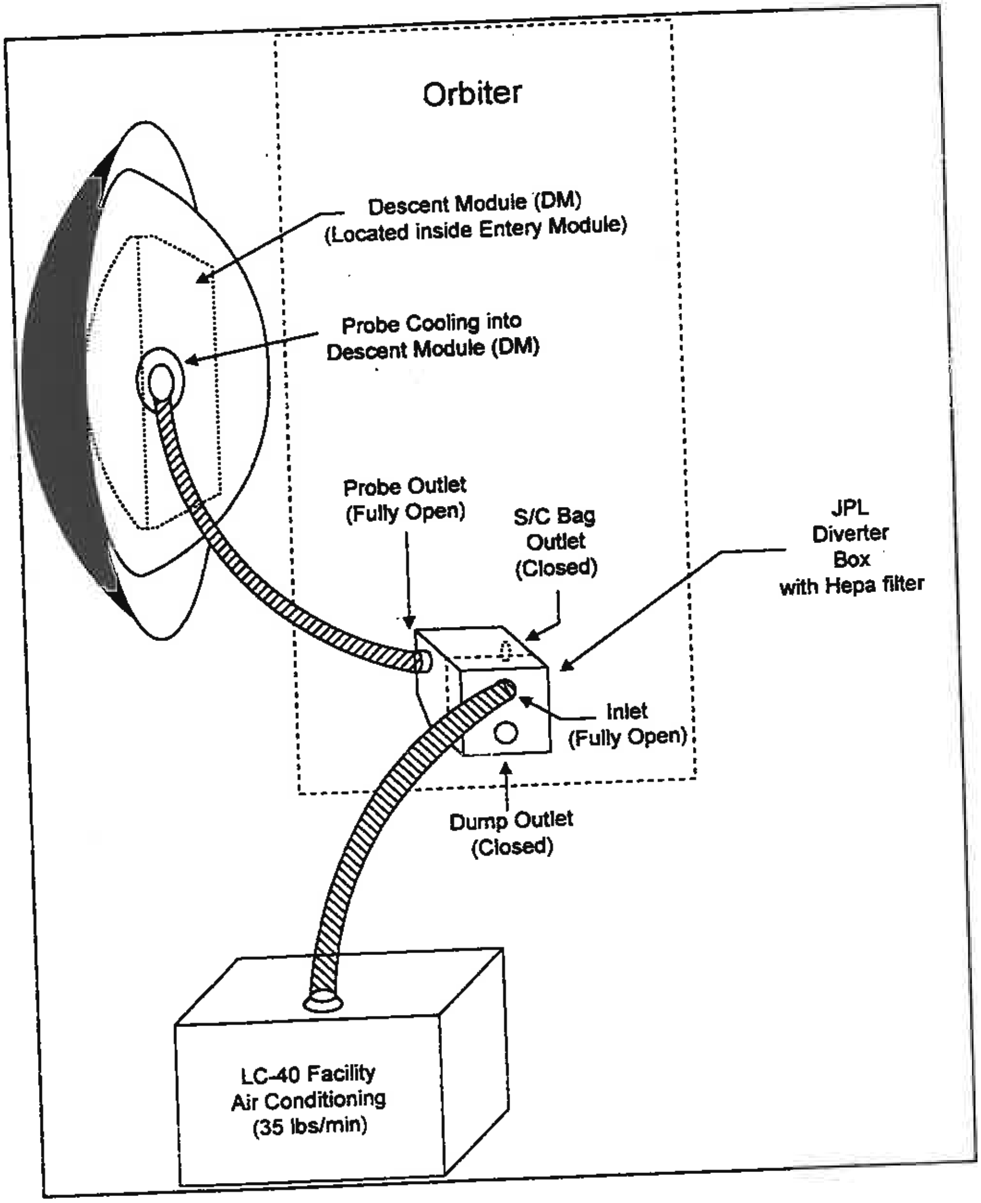
Attachment-2 (Note from P. Hoffman describing the timeline of activities for Probe cooling)

Description:

The configuration of the probe cooling at the PHSF prior to being transported to the launch pad (LC-40) is given in the following figure:



Just prior to the transportation the GLL cooling cart was disconnected from the inlet hose and the inlet valve was closed. During transportation to LC-40 no cooling was supplied. When arriving at LC-40 the S/C bag outlet was open a 1/4 way and the inlet valve was open fully, then the level-7 air conditioning hose was connected to the inlet hose. This was configuration during the lift of the S/C to level-14. Once at level-14 the level-13 A/C hose was connected to the inlet hose. The noise from the diverter box was too loud from a safety stand point so the flow rate of the facility was reduced and the S/C bag outlet was closed. At this time the flow rate into the Probe was approximately 30 lbs/min. This flow rate was too low for the facility to maintain the air temperature control. P. Hoffman called G. Coyle and J. Wirth to state the problem and notify that the flow rate had to be increased to 35 lbs/min. The following figure shows the Probe in the worst case configuration.



On Friday (8/29/97) morning the question was raised to ESA of what the requirement of flow rate into the Probe was. After talking to specialist in Europe it was discovered that the 35 lbs/min was to high. On Friday afternoon the flow rate into the probe was adjusted to ~ 8 lbs/min with ESA's concurrence.

Investigation:

A meeting was held on 1 Sep 97 to determine what damage this high flow rate could do to the internal parts on the Descent Module (DM). The first action was to arrange for a boreoscope to look down the A/C duct into the lower half on the DM. This investigation showed torn pieces on the foam bags and pieces of foam material contaminating the inside of the DM. There was also some questions about the integrity of the seals around the inlets of 3 experiments (ACP, GCMS, SSP). At this point it was decided to disassemble the Probe.

ESA Probe A/C Flow on 8/27-8/29 9/5/97

8/27	9:30PM	Removed GLL Cooling cart A/C A/C Div. Box: Probe Valve fully open, all other valves closed
8/28	2:30AM	A/C Div. Box: Probe Valve fully open Inlet valve fully open S/C bag valve 1/4 open Dump valve fully closed Note: this setting sends roughly 40% of air flow to Probe Level 7 A/C running at 40 lbs/min, 70°F, 34% RH
	4:00AM	Hose from Level 7 disconnected at mid point....zero flow to Probe
	4:15AM	Hose from Level 13 connected Level 13 A/C running at 40 lbs/min, 65°F, 40% RH
	5:15AM	Level 13 A/C set to 30 lbs/min, 60°F, 48% RH Note: flow lowered to reduce noise level
	6:30AM	Level 13 A/C set to 5 lbs/min, 60°F, 45% RH Note: flow lowered to minimize noise during soft mate
	8:15AM	Level 13 A/C raised to 30lbs/min, 60°F, 35% RH A/C Div. Box: Probe Valve fully open Inlet valve fully open S/C Bag valve fully closed Dump valve fully closed Note: S/C Bag valve closed to reduce excessive noise problem
	5:00PM	P. Hoffman notified by A/C shelter that system could not control temperature and RH at 30 lb/min flow. P. Hoffman called J. Wirth to give status and ask about going to 35 lbs/min in order to re-establish control. OK'd by Wirth. Message left for G. Coyle regarding A/C status (Coyle returned call around 7 PM)
	5:30PM	Level 13 A/C raised to 35 lbs/min, 60°F, 42% RH
8/29	6:15PM	Level 13 A/C raised to 40 lbs/min, 60°F, 42% RH A/C Div. Box: Probe Valve fully open Inlet valve fully open S/C Bag valve fully closed Dump valve fully open Velocimeter reading in probe 4" duct 6.3 m/s (~8 lbs/min).

Appendix C

Chronology of Probe Cooling Issue with Comments

Chronology of Probe Cooling Issue with Comments

EVENT	COMMENT	*
09 June 92 IRD - PD-699-080 Rqmt # 62851: ESA shall provide ground cooling.	i.e.: There is no JPL/ESA Probe cooling interface.	
11 June 92 IRD - PD-699-080 Rqmt #61517: Probe GSE shall be responsibility of ESA.	Same as above	
05 July 93 Preliminary flow sizing calculations (Aerospatiale to DASA w/copies to ESA). Concluded flow rate depends on outlet tube diameter to satisfy 500-Pa delta P requirement.		
03 June 94 Probe Ground Cooling Requirements (DASA document to Aerospatiale and ESA) shows tables of flow rates vs temperature of batteries, and concludes: "air mass flow rate shall be in the order of 0.1 kg/s (13.25 lb/min)," identifies cooling configuration as between DM and ENA for launch campaign.		
09 Sept 94 IRD - PD-699-080 Rqmt #61362D, with Table 080:5.3.3-1A, identified ESA as provider of probe internal cooling and defined temperature of air/GN_2 environment around the probe.	Approved 2 Dec 94.	
18 October 94 Initial release of Ground Cooling System Spec (DASA To ESA, HUY-MBB-711-SP-002) shows cooling configuration on pad is between DM and ENA. Analyses use 0.04 kg/s (5.3 lb/min) gas flow rate. No mention of limits.		
30 November 94 QPM - Launch Vehicle Integration Issues presentation addresses probe cooling requirements. Identified high risk of exceeding 12 hours maximum w/o cooling during transport to pad and hoisting. Option 3 (using pad A/C with diverter box to reduce flow from 75 lb/min to ~10 lb/min during hoist and initial time in UES) was selected. AI O/P 021-055 assigned to ESA to "provide the probe ground cooling hose diameter and fitting detail, and the minimum and maximum flow rate."	Responsibility for providing probe cooling air on pad prior to and during hoisting operations changed to JPL. IRD Reqmts (First two items above) could have been changed at this time to reflect this new responsibility, or identified as necessary for change when Action Item was closed.	O
06 Jan 95 Phase 2 safety review AI closure. JPL and ESA concur that JPL will supply probe cooling at pad prior to and during hoisting operations with UES Level 7 air conditioning.	Flow rate was "expected to be approximately 0.075 kg/s (10 lb/min) with ESA to finalize"	

*Note: Far right column identifies opportunities to have avoided the problem (O).

EVENT	COMMENT	*
26 Jan 95 Fax (from Aerospatiale Thermal Engineer to JPL Mechanical/Thermal Engineer) in response to QPM action item O/P 021-055, which requests "ESA to provide the probe ground cooling hose diameter and fitting detail, and the minimum and maximum flow rate." Fax says "gas flow rate to be used for venting between DM and ENA is still under evaluation. Present value used by DASA in calculations is 0.04 kg/s (5.3 lb/min)....Limit is 0.3 kg/s (40 lb/min) to avoid damage.... Velocity is 16 m/s (assuming 6-in. hose). Flow rate ... will be confirmed after tests...on STPM." Attached drawings showed 6-in.-diameter hose.	Policy was to copy JPL Probe Integration Manger on all formal correspondence from ESA to JPL. This fax as an action item closure should have followed this policy. However, it was only sent to the technical cognizant engineer.	O
31 Jan 95 AI O/P 021-055 closed by JPL and ESA agreement based on above Aerospatiale fax.	1) JPL/ESA accepted this fax as closure when it was not written like a reqmt, but more like a status. It included work that still needed to be done. Furthermore, the JPL probe integration manager did not have a copy of it. (Copy was only to the technical cognizant engineer.) 2) AI closure should have identified the IRD as an affected document. 3) Alternatively, an MICD could have been written. 4) Plan for confirmation of values should have been tracked in another AI. 5) Fax assumed a 6-in.-diameter hose (not explicitly called out) The air supply tube was later established at 4 in. dia from the diverter box and later ESA changed the outlet to 1.5 in. No one thought about the associated increased flow velocity, upon which the original calculations were based, and hence a potential violation of an implied and unnoticed requirement. Addressing any one of the "problem" items would probably have eliminated this as an issue.	O O O O O
03 March 95 IOM JPL Thermal Engineer to Fabrication Section. Identifies need to design diverter box that will supply no more than 40 lb/min to Probe, minimum not known (expects minimum to be in 10- to 20-lb/min range).	LC-40 Facility air conditioning could be set to 0.3 kg/s (40 lb/min).	

EVENT	COMMENT	*
22 March 95 QPM. Identified difficulty in accommodating HERAEUS cooling cart in PHSF and LC-40. AI assigned to JPL to assess compatibility of ESA cart at JPL, PHSF, and LC-40. AI assigned to ESA to assess adequacy of GLL cooling cart.		
Sept 95 The JPL Mechanical Thermal Interface Engineer went to another project. He had been the primary engineer working the air conditioning interface.	At personnel changeover, this problem could have been avoided if finalizing this interface had been identified as an open item to be tracked.	O
29 Sep 95 Rev. A of ESA Cooling Cart Spec - Shows flow rate of 0.04 kg/s used for velocity and pressure calculations. Defines cooling on pad as between ENA and DM. Does not define maximum flow rates. This is a DASA spec to ESA.	Careful JPL review might have caused an alert regarding the desired (required?) flow rate, even though this wasn't an official JPL/ESA interface requirement document.	O
03 October 95 QPM - ESA accepted use of GLL cooling cart. This was now baseline to use GLL cart at JPL, PHSF, and after hoisting at launchpad.	ESA was responsible for GLL cooling cart, so ESA was still responsible for Probe cooling except for during the pad hoisting operations.	
18 March 96 QPM - Probe Cooling Plan vu-graph package presented. Concentrated on hoisting/hose lengths, leading to Trailblazer exercise. Says facility air will go to probe and space vehicle bag. Says "Flow rates will be tested," but did not quantify any planned flow rates. Trailblazer set point of 50%/50% reported to have been orally mentioned to ESA personnel by JPL mechanical/thermal Cog. E. There was no concern expressed.	Focus of JPL was on flow rates and temperature available from the facility, knowing the diverter box could be set to any smaller amount that ESA would desire. If presentation had been more specific or time had been taken to ask in-depth questions, problem would have been prevented.	O
April 96 Trailblazer took place. ESA engineers concentrated on probe closeout access issues, and do not remember discussing diverter box operation.	If anyone had asked about desired flow rate to probe during this exercise, problem would have been avoided.	O
April 96 There never were measurements to validate the flow rate split. It was not deemed necessary since no requirement for flow rate was specified.	ESA and JPL treated this casually. There is no explanation for this.	O
01 May 96 Launch Vehicle System Integration Panel Meeting. Probe cooling plan and recommendations from Trailblazer activity presented. Mentions use of "A/C box valves to set desired flow rate to Probe" in UES. Also recommends addition of "flow rate measuring capability to probe portion on A/C box."	No mention of what the "desired flow rate" was. Again, saying "TBD flow rate (to be specified by ESA)" would have been a flag for someone to ask when the TBD would be filled in.	O
06 June 96 QPM - the May 1 Probe Cooling Plan vu-graph package was presented at QPM.	Same comments as for 1 May 96. All the proper ESA and JPL people were involved.	O

EVENT	COMMENT	*
20 June 96 Probe Cooling Plan presentation for Titan Ground Operation Panel. "reset A/C flow at diverter box to ESA value". Notice no number presented.	Saying "set to TBD (ESA value to be supplied)" would have solved the problem.	O
Dec 96 LOM sent to JPL for comment. Did not contain anything specific about the probe air conditioning requirements. Did show closeout of DM at pad, but did not say anything specific about air inlet tube removal.	LOM was not treated as a requirements document by the program. ESA and JPL had different interpretations of the LOM. Because of this, JPL did not believe a critical review was required, and ESA did not insist on comments from JPL.	
After April 96 Trailblazer recommendation for a flow measuring device was not implemented due to a cost cut exercise. Rationale was that a flowmeter was too expensive, and not necessary since there was no specific reqmt, and it was perceived that the maximum air could not damage the probe and the value could be set to any ESA requirement, but it didn't matter much.	If the flow measuring device had been added, someone might have raised a flag.	O
March 97 QPM. The same Probe Cooling Plan vu-graph package from June96 was presented again. Did not say how flow was planned to be set. Did not request input from ESA. Did indicate variable capability up to 40 lb/min max.	Being more specific (saying "set to TBD (ESA value to be supplied)") would have solved the problem. Someone could have asked a question, but no one thought to.	O
March 97 ESA ATLO lead transferred to another project.	Some "corporate knowledge" lost at that time.	
March 97 Probe FAR (Flight Acceptance Review). Neither the missing requirement or the expected airflow was highlighted, but the 0.04 kg/s (5.3 lb/min) value was in the (very thick) package.	This is the kind of review where one would hope problems like this would be discovered. Unfortunately, it wasn't. The item apparently was too buried in the documentation.	O
30 April 97 Probe HRCR Item 25 (Instruction/constraints for safety, handling, test, packaging, storage, and shipping). Did not identify an air velocity limit. ESA PA never thought about too much air.	There should have been an analysis for what could go wrong w/too much air (i.e., if the valves were set too high) or if the LC-40 supply was too high.	O

EVENT	COMMENT	*
Spring 97 SECR for Diverter Box said mechanical FMECA not required. (FMECAs are not usually required for ground mechanical I/Fs). The "active" nature of this interface (via the airflow) and its damage potential were not recognized.	The change in probe internal cooling configuration at LC-40 changed the impact. Otherwise, not having a mechanical FMECA was reasonable to JPL, since the max air expected from the facility was 40 lb/min, which matched what JPL understood to be the max allowed by the probe. Hence, "No problem." ESA had never mentioned a concern about too much air. Hence, the "No FMECA required" was not challenged at the SECR review. Unfortunately, no one asked about an MICD with the probe to match the MICD to the facility. Someone could have, and stopped this problem from occurring.	O
28 July 97 Probe IRD Reqmt Verification Matrix categorized rqmts #62851 and #61517 (ESA responsible for cooling) as "N" meaning "verification not needed."	This would have been another opportunity to update the IRD and/or ask where the cooling interface requirements are documented and verified.	O
Summer 97 Procedure for setting diverter box valves - The diverter box set points, planned by JPL to be 20 lb/min air to the probe were not specified in the procedure. The procedure relied on the Cog E and said "Set acceptable flow" to probe. It did not specify the value. This was accepted, since the Cog E supplied the details, and also would do the work. The Cog E's previous experience of working w/out detailed procedures made this seem normal. Also, this was not overruled by supervision or the procedure review process. There was no required response from all parties prior to a procedure sign-off. Author was responsible to get it reviewed by relevant areas. Rev. B did not have an ESA person on the list. There was no request by ESA to be on the list, and no JPL perceived need for ESA review. The criticality of the diverter box setting was not understood.	The procedure review process doesn't work the details, and everyone was passive regarding requirements. No one realized that leaving out this detail would lead to inadequate review of the procedure and would lead to an unfortunate sequence: 1. JPL engineers and managers would not be triggered to ask "what is the valve going to be set to, and why" 2. ESA engineers, would not review the sequence and potentially question the valve setting. 3. ESA PA would not be present during the valve setting. 4. JPL PA would not question the valve setting. 5. ESA PA would not be on the list to participate/observe on the pad. 6. When the Air Force reduced the number of "observers" on the pad during the critical hoisting procedure, ESA would not be motivated enough to contest ESA exclusion from the pad operations.	O

EVENT	COMMENT	*
Aug 97 Probe internal cooling configuration - It is not clear when the decision was made to keep the probe cooling configuration internal to DM rather than following the previous plan of switching to cooling between the DM and ENA for the on-pad cooling. Some key ESA personnel, key Aerospatiale personnel, and key JPL personnel were unaware of the change. Some others were aware of it, but did not recognize the significance. The board has been unable to discover how or when the change was made. No one seems to know. It was apparently deemed an internal probe operations detail that had no effect on the interface, and an informal change process at ESA was allowed.	Proper configuration management procedures would have required exposure and review of this changed ESA plan, and would have likely triggered an alert and avoided the problem. A more disciplined procedure-writing process would also have caught it. Also, had the change in plan not been made (i.e., if the air had gone between the DM and ENA), there probably would have been no probe damage even with the higher (than ESA expected) air flow.	O
Aug 97 One-on-one meeting between JPL and ESA. Went over June 96 Probe Cooling Plan package one more time.	Saying "set to TBD (ESA value to be supplied)" would have solved the problem. No one even mentioned "TBD rate" or "planned rate," just "ESA desired rate." JPL was thinking "up to 0.3 kg/s (40 lb/min)," and ESA was thinking "the same as the GLL cooling cart (5 to 10 lb/min)". Thus, they thought they were agreeing, but they were talking "past" each other.	O
About 27 Aug 97 JPL Cog. E noticed the tube going into the DM, but did not associate that with a possible reduced flow rate requirement. Most JPL people thought the cooling was between the DM and ENA.	Writing or saying the numbers across the interface would have solved the problem.	O
27 Aug 97 ESA mechanical/thermal lead was just returning from Europe when S/C was hoisted to top of L/V.	Had he been back earlier, he might have raised a question about the valve set point plan.	
27 Aug 97 Move to LC-40 - No ESA person on pad at time of incident.	They were not on the manloading list, since the procedure didn't say anything about the probe. ESA did not contest their not being there.	O
27 Aug 97, 9:30 p.m. Removed GLL cooling cart; probe valve full open, S/C bag valve quarter open, inlet valve closed, dump valve closed.		
28 Aug 97, 2:30 a.m. Arrive at LC-40. Open inlet valve, attach A/C hose from level 7 (40 lb/min from facility, ~18 lb/min to probe, remainder to S/C bag)	This airflow to probe is three times higher than desired, and may already have caused damage when injected into the DM.	
28 Aug 97, 4:15 a.m. Switch to level 13 A/C hose. (facility air at 40 lb/min)		
28 Aug 97, 5:15 a.m. Level 13 A/C set to 30 lb/min to reduce noise		

EVENT	COMMENT	*
28 Aug 97, 6:30 a.m. Level 13 A/C reduced to 5 lb/min to reduce noise during soft mate.		
28 Aug 97, 8:15 a.m. Level 13 A/C raised to 30 lb/min; excessive noise; closed S/C bag valve. All 30 lb/min going to probe.	At the pad, when noise was a safety concern, air to probe was increased rather than air being dumped to outside. This was because all previous known concerns were that the probe batteries might get too hot; never that increased flow might cause damage. By now, the damage was already done, unfortunately.	
28 Aug 97, 5:00 p.m. A/C system could not control temperature and relative humidity at 30 lb/min flow rate. OK'd to increase flow to 35 lb/min. All flow still routed to probe. Call placed to ESA engineers to confirm acceptability of flow rate.		
29 Aug 97 At the time of the incident, ESA didn't know immediately that 35 lb/min was too much, but they knew it was more than they expected, and were concerned.	If a maximum had been known and documented, the earlier ambiguous communication would probably never have happened.	
29 Aug 97, 6:15 p.m. Level 13 A/C raised to 40 lb/min; probe valve full open, inlet valve full open, S/C valve closed, dump valve full open. Velocimeter reading in probe 4-in. duct = 6.3 m/s (~ 8 lb/min)		
September 97 When returning the S/C to LC-40 after repairing the damage to the probe, the cooling configuration within the probe was changed to between the DM and ENA, and the airflow supplied to the probe was limited to ~ 8 lb/min.		

Appendix D

Illustrated Table: Detailed application of the ground cooling system

(Table 2 from *Ground Cooling System Specification,*

Document No. HUY-MBB-711-SP-0002

Issue 02 Date: 24.11.94

Revision A Date: 29.09.95)

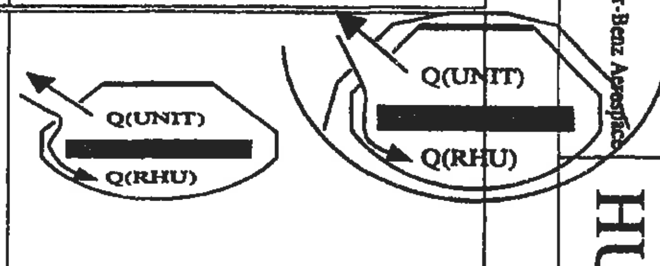
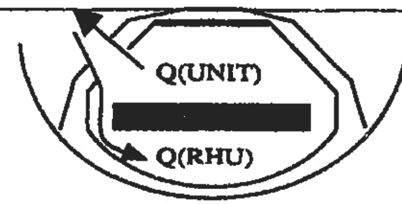
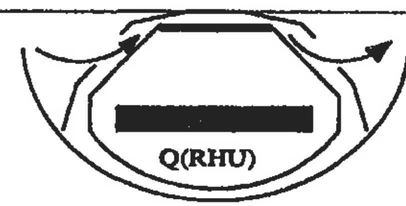
No.	Model	Used at	Purpose of Use	Probe Configuration Geometry	Probe Configuration Dissipation	Cooling	Cooling configuration
4	FM	USA (clean-room)	RHU integration and electrical check out tests	DM alone or fully intgr.Probe	all RHU's all Units	active	
5	FM	USA (clean-room)	RHU integration for a long storage period (due to batteries)	DM with ENA	all RHU's no Units	active	
6	FM	USA (in free environment)	on way to launch pad on launch pad (probe is mounted on orbiter)	fully integr.Probe on Orbiter	all RHU's no Units	active	

Table 2: Detailed Application of the ground cooling system